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**VOLUME 82**

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CONTENTS

October, 1956

Papers

	Number
Modernizing a Texas Highway with Concrete by Allan L. Chollar .....	1074
Economics of Self-Protection Against Flood Damage by J. C. Young .....	1075
Foreign Operations of the Bureau of Public Roads by A. C. Taylor .....	1076
The Highway Spiral as a Centerline for Structures by Paul Hartman .....	1090
Discussion .....	1093

THE UNIVERSITY OF CHICAGO  
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DEPARTMENT OF CHEMISTRY

REPORT OF THE  
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MODERNIZING A TEXAS HIGHWAY WITH CONCRETE<sup>a</sup>

Allan L. Chollar,<sup>1</sup> M. A.S.C.E.  
(Proc. Paper 1074)

ABSTRACT

This paper outlines the design and construction procedures involved in planning and constructing concrete resurfacing over a 16 foot concrete pavement 34 years old. The new 24 foot pavement is part of the 4-lane divided modernization of this highway. Construction details of longitudinal and transverse jointing procedures are described.

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Highway Engineers everywhere are racking their brains with the problem of rehabilitating existing roads that have become obsolete because of increased traffic volumes and wheel loads. Many of these roads are narrow concrete pavements that still have structural value. The problem is compounded because a considerable additional cost is involved if the concrete pavement is removed and disposed of.

State Highway 347 south of Beaumont in Jefferson County, Texas consisted in part of an old 16 foot wide concrete pavement 6 inches thick. The traffic volume on this section of road was 5000 to 6000 vehicles per day. It goes without saying that during peak hours traffic congestion was almost unbearable. The greatest congestion occurred during shift changes at the refineries and industrial plants located in the area.

Concrete pavements in the South Texas area had been rehabilitated by several methods during the last ten years. Both light and heavy asphaltic concrete overlays had been used. Heavy (up to 12 inches) flexible base overlays had been constructed where such grade raises could be permitted. Extensive undersealing and leveling by mud jacking had been done both with and without overlays. In one case a penetration seal was placed on the concrete slab after undersealing and leveling with an asphalt slurry.

The Texas Highway Department had practically no experience with

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a. Presented at the Dallas Convention of the A.S.C.E., Feb. 16, 1956.

1. Supervising Designing Engr., Texas Highway Dept., Austin, Tex.



Fig. 1. The Old Road Prepared for Resurfacing.

concrete slab overlays. In fact, very few jobs of this type were available in Texas for study and comparison. Perhaps the reason, so few jobs had been constructed, was the fact that, in most cases, no satisfactory detour for the existing traffic could be provided without excessive cost. Then too, in areas where parallel facilities were available for a detour, a grade raise could not be permitted; in fact, a lower grade for a street section would be required in most cases.

The present and anticipated traffic volumes on State Highway 347 indicated a four-lane divided highway was needed and this type facility was authorized. This solved the detour problem. Traffic could use the old road while parallel traffic lanes were being constructed. After the new traffic lanes were completed, traffic could use the new lanes while the old road was being rehabilitated, see Fig. 6.

The right-of-way width was 200 feet. This width permitted a rural type cross section and a grade raise was not considered objectionable.

The Highway Planning Survey Division of the Texas Highway Department studies, weighs and reports on the wheel loads of vehicles using Texas highways. "Wheel Loads on Texas Highways," published in 1953, is the basis for evaluating and determining the wheel load to be used for individual projects. The wheel load map for the Jefferson County area indicates that the average of the ten heaviest loads expected on State Highway 347 at the present time is 12000 pounds. For long life the design wheel load selected will usually be higher than the wheel load indicated by the map, and a selection is made on the basis of experience and judgment.



Fig. 2. Setting Forms.

The Texas Highway Department's usual practice is to estimate Westergaards "k" factor for the subgrade under concrete pavements after making triaxial tests of so called undisturbed samples of the subgrade. These samples are taken from a depth of zero to fifteen feet below the elevation of the pavement in cuts and on low fill sections. On high fills prepared test samples are used. Triaxial tests are also used to design flexible bases.

A discussion of the methods used to estimate "k" and to design flexible bases is published in Book II of "Plan Preparation" published by the Texas Highway Department. The Materials and Tests Division by Administrative Circular 43-50 transmitted to District Engineers and Engineer Managers three articles on triaxial test methods and the application of test results. These references are cited for the benefit of those who may wish to review these methods.

The Texas Highway Department Standard Specification Item 320 requires that the concrete for pavements be designed with the intention of producing a minimum average flexural strength of 650 pounds per square inch at the age of seven days using a standard testing machine in which the load is applied at

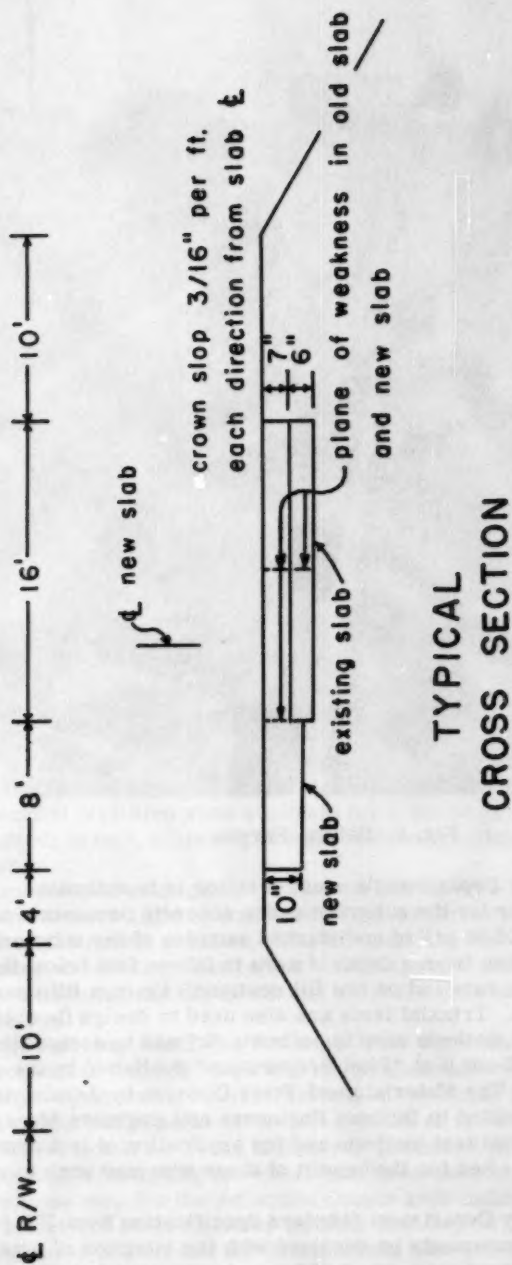


Fig. 3

the center of the beam span. It is customary to assume that concrete will gain 10% of its seven day strength at the age of 28 days. On this basis the strength of concrete is assumed to be 715 pounds per square inch when stresses from loads are calculated.

The Texas Highway Department has not developed a method for the design of concrete resurfacing. An empirical formula for determining the depth of concrete resurfacing has been reported by the Portland Cement Association.

The formula is  $D_r = (D^{1.87} - CDe^{2.1/2})^{1/2}$ .  $D_r$  is the depth of resurfacing in inches,  $D$  the required thickness in inches of a single slab for the same conditions of loading and subgrade, and  $De$  the depth in inches of the existing slab. "C" is a constant whose value is assigned on the basis of the condition of the existing slab and usually varies from 0.35 for slabs in poor condition to 1.0 for slabs in excellent condition. I understand that this formula was originally proposed by Mr. R. R. Philippe, while he was employed as Director of the Ohio River Division Laboratories, Corps of Engineers Department of Army.

When the existing sixteen foot concrete pavement was examined, its structural condition was classed as fair. Maintenance had been excellent, and gravel shoulders had been placed on both sides of the old slab.

Estimates of cost indicated the cost of a concrete overlay compared favorably with the cost of alternate types of construction that were considered to be structurally equal to a concrete slab overlay. A cross section of the concrete overlay is shown in fig. 3.

It will be noted from the typical cross section that the edge of the overlay

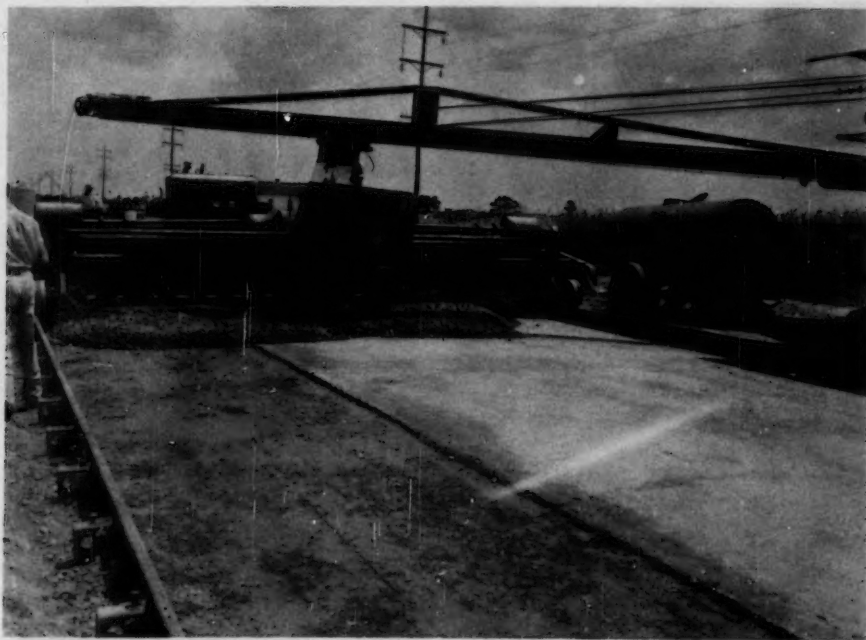


Fig. 4. Longitudinal Joint Machine and Bull Float.

slab was placed at the edge of the existing slab. During construction, it was found that the old slab was not exactly true to line. See Fig. 1. For construction convenience the new slab was shifted one foot thereby over-lapping the existing slab. See Fig. 2. This change required a slight modification of the contraction joint form that might have been avoided by planning the overlay slab to overlap the existing slab.

Two longitudinal joints were required by the plans. One longitudinal joint was located above the center of the old sixteen foot concrete slab. See fig. 4. The other was placed at the edge of the old sixteen foot slab. Alternate types of longitudinal joints were permitted by plans. The type used by the contractor was the cut and coated groove formed by cutting the fresh concrete and coating the sides of the cut with curing compound. A 1/2" round deformed bar 3'-0" long spaced at 2'-6" centers was placed across the joint to tie the two slabs together.

During an inspection of the project on January 12, 1955, it was noted that some of the longitudinal joints were operating and some were not. It is believed a crack will develop at both of the weakened planes along the longitudinal joints after a few wet-dry cycles have occurred.

The pavement design specified that contraction of the pavement would be relieved by contraction joints spaced at fifteen foot centers transversely across the pavement. No expansion joints were used. Contraction joints were formed by vibrating a metal contraction joint form into the fresh concrete pavement with a machine traveling along the forms. The specifications permitted the form to be staked to the subgrade, but the contractor elected to vibrate the form into place. The joint form is made of 28 gage galvanized

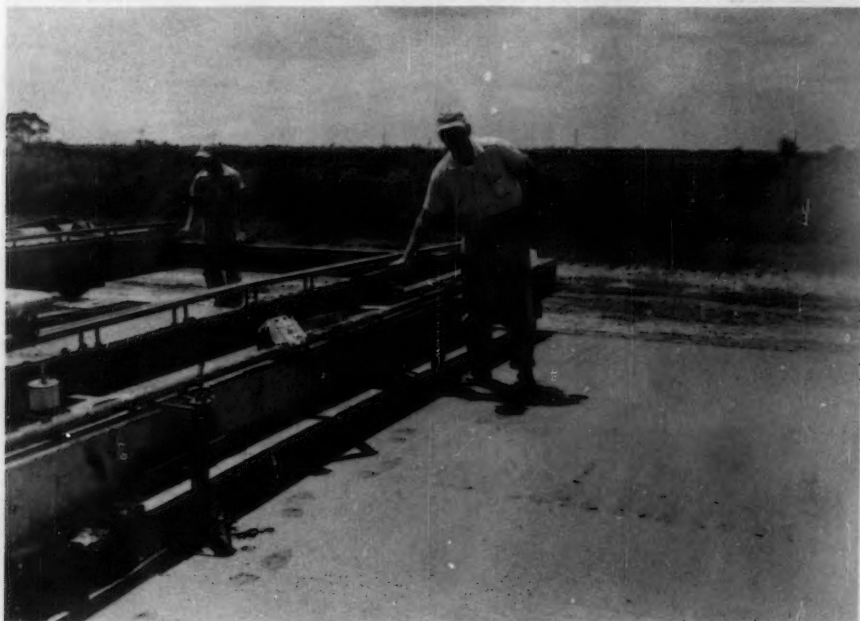


Fig. 5. The Contraction Joint Being Vibrated into the Fresh Concrete.

metal shaped so as to form alternate tongues and grooves in the concrete and the form is left in the concrete, see fig. 5. The tongues and grooves are circular in cross section with a diameter of one inch. This shape permits contraction without appreciable loss of load transfer when the joints are spaced at not more than fifteen feet on centers. The shape of the contraction joint also permits slight vertical movement at the joint to relieve warping stresses and permit allowable deflections. In this respect, the joint resembles two interlocking gears. The top 1 3/4 inch section of the metal form is not curved. The top of the form is placed as close to the surface of the slab as practical and not more than 1/4 inch from the surface. The bottom of the form is designed to be placed one inch from the subgrade.

Each fifteen foot panel was reinforced with welded wire fabric placed five inches from the top of the slab. Longitudinal wires were No. 1 on six inch centers, and transverse wires were No. 7 at twelve inch centers. A reinforcing steel mat was permitted as an alternate at the option of the contractor but was not used.

The paving design assumed that the reinforcing steel would prevent any cracks that might form from opening. No allowance was made in the design for any stress relief the reinforcement might provide.

The construction of the project was performed under the general supervision of Mr. W. E. Simmons, District Engineer for the Texas Highway Department, and under the direct supervision of Mr. E. R. Young, Expressway Engineer. The District Office and Expressway Office are both located in Beaumont. The contractor was the Worth Construction Company of Fort Worth, Texas.



Fig. 6. A Close up of Paving Operations.



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ECONOMICS OF SELF-PROTECTION OF HIGHWAYS  
AGAINST FLOOD DAMAGE

J. C. Young,<sup>1</sup> M. ASCE  
(Proc. Paper 1075)

SYNOPSIS

Flood-protection economics for highways must take into account engineering, legal and public interest considerations, both tangible and intangible in character. To reach sound decisions, it is important to know the limitations of economic analysis. What follows is an appraisal of the factors involved, and the logic of their application.

INTRODUCTION

A century ago, W. M. Gillespie, Professor of Civil Engineering at Union College, stated, "A minimum of expense is, of course, highly desirable, but the road which is truly the cheapest is not the one which has cost the least money but the one which makes the most profitable returns in proportion to the amount which has been expended upon it." Even 100 years ago, Professor Gillespie recognized the need for economic analysis in highway problems.

This paper will cover the application of economic analysis to problems of self-protection of the highway against flood damage. In the past, the engineering evaluation of risk against capital investment has been limited mostly to bridges and major structures. This limitation stemmed mainly from the low capital investment and rapid obsolescence of early day highways. Today, the permanent character of freeway and expressway construction coupled with the large investment tends to make a more complete analysis of the risk and investment factors profitable.

Any state highway system, because it is a complete network of highways covering a State, is almost certain to be involved in every flood problem within the State. There are few streams that fail to intercept at least one state highway, and in many cases a major flood may involve several highway crossings of the same stream. The degree of protection against flood damage

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must follow a consistent policy throughout the system as a whole. Thus for roads of equal importance, it would be poor practice to provide against a 10-year storm frequency in one place and a 20-year frequency in another particularly when crossings of the same stream are involved. At the same time, the degree of flood protection should be commensurate with the degree of damage to the road that is likely to be incurred. The economic analysis, then, is instrumental in achieving consistency as well as in comparing the worth of protective measures.

Since the subject of flood protection economics covers a wide field, it is expedient to limit this discourse. For one thing, it appears unproductive to look for game in the field of procedures. There is better hunting elsewhere, namely, in the factors to be considered. There are many uncertainties in the economic analysis which need inspection. They stem from incomplete data, inadequate engineering knowledge of flood hydraulics, and the unsubstantial character of intangible considerations. To achieve sound decisions, it is important to know the limitations of economic analysis. What follows, then, is an appraisal of the factors involved, both tangible and intangible, and the logic of their application to problems in flood protection economics.

Any illustrations used in this discussion will refer to California conditions since that is the area with which the writer is most familiar.

### Effect of Flood Type on Economics

The economic analysis is affected substantially by the type of flood. Because of the different degrees of risk they impose, the types of floods likely to be encountered must be identified. These are the types:

- a) Inundation from backwater rising to a level above the highway; and
- b) Flooding by a freshet overtopping the highway.

Flooding by inundation often occurs where large streams cross the highway. Such floods can be fairly accurately predicted as to frequency and duration because adequate hydrologic information is usually available for such streams. In other words, since flooding resulting from large streams is more readily predictable, the economic analysis is more reliable.

The freshet type of flood, or the flash flood, is typical of semi-arid regions. It usually occurs in small watersheds, particularly on the steep alluvial fans in Southern California. Although it is of short duration, it carries the threat of high property damage and loss of life. In the most northerly reaches of California, where a yearly precipitation ranging from 40 to 100 in. can be expected, a flood runoff between 100 and 400 sec ft may develop from an area of one square mile. But in the semi-arid portions of Southern California, where the yearly rainfall varies from 2 to 15 in. as much as 1200 sec ft of runoff can materialize in an equal area. Any drainage problem is likely to be complicated by infrequency, short duration and, often, by the absence of hydrologic information. Thus, in semi-arid regions, because of uncertain flood predictability, the economic analysis is apt to be less reliable.

### Methods Employed in Economic Analyses

It is well to admit at the outset, that public highway economics today is a rather inexact science. Certain details of importance, such as the unit value

of time and the value of auto accidents need more searching study. Indeed, many authorities in highway economics will not admit that any value whatever can be assigned to time in the case of passenger cars although most will agree that some value can be assigned when considering commercial vehicles.

There are two methods of analysis used by the California Division of Highways. These will be identified as Method "A" and Method "B" for purposes of discussion.

#### Method "A"

A simple method commonly used for evaluating a drainage improvement is a comparison of the total probable annual cost of physical damage to the highway under existing conditions against the annual cost of adequate protective measures. Alternative designs also may be compared in this manner. This method applies usually to roads with low traffic and is useful in appraising the worth of minor improvements involving a small outlay, such as the enlargement of a small culvert, a minor raise in grade, or minor erosion protection.

#### Method "B"

For improvements of larger scope, particularly on roads with high traffic volumes, in addition to estimating the physical damage that might occur if a certain protective measure is not taken, it becomes necessary to appraise the benefits of the protective measure to the users of the highway. Road user benefits or savings are the difference in annual costs to road users traveling over the highway under existing conditions and under the conditions which will prevail after the improvement. These road user benefits include vehicle operating costs, value of lost time, accident costs, and sometimes a strictly arbitrary value assigned to comfort and convenience. The annual road user benefits plus the annual cost of physical damage under existing conditions are balanced against the annual cost of the flood protection measures under consideration. This type of analysis is useful when alternative drainage improvement plans are being considered since all of the alternatives may not result in identical user savings.

### Factors Considered in the Economic Analysis

The economic justification of flood protection works must be made on the basis of two kinds of factors: tangible and intangible.

The key to this classification is: a) if the item can be appraised within reasonable limits in terms of dollars, it is a tangible factor; b) if it cannot meet this test, it is an intangible. Following is a list of factors which fall into these categories:

#### 1) Tangible Factors

- a) Replacement of embankment or structure.
- b) Replacement of pavement and shoulders.
- c) Clean-up and traffic control expenses.
- d) Placing and removal of detour or temporary drainage facilities.
- e) Replacement of erosion control planting.

- f) Extra travel distance costs.
- g) Accelerated pavement deterioration by subgrade saturation.

## 2) Intangible Factors

- a) Time-delay costs (these may be treated as tangibles in some cases).
- b) Conflicting public interests.
- c) Accidents directly attributed to floods on the highway.
- d) Legal responsibilities of the highway agency.
- e) Future price trends.
- f) Comfort and convenience.
- g) The degree of risk to be accepted.

The tangible items, (a) through (e) inclusive, can be easily applied in terms of dollars for purposes of economic analysis. No further discussion is believed necessary because they are clear cut. The remaining factors will be covered below.

### Extra Travel Distance

Extra travel distance due to flooding of the highway is a tangible value because it represents a measurable out of pocket operating cost to the road user. It is generally an important yardstick in measuring the worth of flood protection measures.

### Pavement Deterioration

Another factor worthy of discussion is accelerated pavement deterioration due to flooding. When an old pavement is involved, the presumption that damage will occur is well founded. If, on the other hand, it is a pavement that was built and designed to modern standards, saturation of the subgrade should have only minor effect. Because it can be treated as a definite cost item, it is regarded as a tangible consideration.

### Intangible Considerations

A complete discussion of all the intangible factors is beyond the scope of this presentation. By their very nature, they defy the assignment of dollar values. Some factors can not be evaluated because their estimated value varies between wide extremes depending on the source of information. It is much safer to regard such items as intangibles. Other factors, which obviously cannot be given a value, may have one effect in one situation and the opposite effect in another. Such factors, then, are properly considered after comparisons of the tangible factors, or the dollar values have been made.

### Time Factor

The time or delay factor has been listed as an intangible. As previously mentioned, it is one of the most controversial factors in highway economics. Because of the difficulty in arriving at an acceptable value of lost time, this factor seldom can be used as an absolute yardstick by which to measure how much to invest in flood protection.

### Public Interest

Of all the intangibles, the most nettlesome factor is conflicting public interests. Public interest is not reflected as an attitude or a force that always acts in one direction. In fact, in a drainage situation, the interests of the traveling public are frequently diametrically opposed to those of the affected property owners. While the obligation of the highway engineer is primarily to the highway user rather than to the property owner, it becomes his duty to evaluate the interests of both groups.

A typical situation of this kind would be to determine the height of fill for an improvement where a highway carrying heavy traffic is overtopped by storm water and upstream property is flooded about once a year. In the interest of the highway user, it would be desirable to keep the road dry at all times by holding to a high grade line and allowing upstream property to be flooded. From the property owner's viewpoint it would be desirable to build a bridge and pass the whole flow under the highway without upstream ponding. This solution would be a benefit to both the property owner and the road user, but it would be the most costly. A reasonable and economical solution would be to accept a lower fill and build a culvert of sufficient capacity to keep upstream flooding within tolerable limits. This means accepting a reasonable risk of flooding which would incur small damage to both upstream property and the highway, say once in 20 yr. This is not a serious inconvenience to the road user. Thus, the decision for or against full protection of the highway against flood damage is heavily influenced by an intangible: public interest or public opinion.

### Accidents

A reasonable annual cost of property damage and loss of life caused by accidents involving motor vehicles and directly attributable to flooding of the highway is difficult to establish. In many cases, the accident record is insufficient to clearly show that pavement flooding is causing accidents. It is reasonable to assume that even without a single reported accident within a given period of time a nonassessable accident potential would exist, for if given more time, accidents would occur. The procedure then would be to use this assumption as an intangible value for or against the project, after the dollar items have been appraised. On the other hand, in situations where a definite record exists, the costs of accident losses may be applied if desired. Since the unit cost of accidents can vary depending on the source of information, such costs must be applied with care. In general, it is advisable to treat this factor as an intangible.

### Legal Considerations

While legal considerations are classified as intangible they enter very strongly into the analysis of drainage projects.

In any drainage improvement where adjacent properties are affected, it is proper to include in the estimates of damage any items for which the highway authority would be held liable. Frequently, what appears to be an inconsequential improvement becomes a major undertaking when the legal aspects

of the situation are considered. Should legal considerations dictate a major improvement where only minor changes were initially contemplated, the more exacting method of analysis, Method "B", may be required particularly if the traffic volume is large.

### Future Price Trends

The cost of replacement must be recognized in any analysis. Specifically, the questions which confront the engineer are: What will be the future cost of replacement and what present cost of flood protection is justified to prevent future destruction of the highway plant? Replacement cost estimates depend on future price levels. Hence, they are not as authoritative as past and present costs. Thus a culvert design which exceeds an alternative design by a small margin cannot be hastily rejected solely on the basis of replacement cost. The choice may depend on other factors.

### Comfort and Convenience

Comfort and convenience are intangible benefits. Although they cannot be given a definite value, these benefits are real and merit consideration. Proof of this is the many drivers attracted to a freeway despite the fact that, in many cases, there are apparently no savings in time or distance. The drivers' reasons may be many and varied: It is easier driving over the freeway, other routes are congested, there are no grade intersections on facility, stop and go driving is absent, there is less strain on the driver, etc. This points to a road user preference that is beyond the value of time and operating cost savings. Highway engineers accept this logic but find it difficult to assign a definite numerical value to comfort and convenience. Therefore, this factor is best applied as a plus or minus value, as the case may be, after the tangible factors have been weighed.

### Degree of Risk

A fundamental tenet of the economic analysis is that the investment must be consistent with the benefits. This implies the acceptance of a risk. The amount of damage or risk that can be reasonably accepted is a variable depending on the situation. As a matter of economics, the degree of risk depends on the volume of traffic using the road and the value of the investment to be protected. Since the annual amount of damage is frequently a matter of record it is readily assessable and, as mentioned before, is a tangible factor.

The concept of accepting a future risk requires estimates of future damage which are less authentic for two reasons. First, this involves forecasting future construction costs. Second, the degree of risk may change, particularly in an expanding economy, as in California at this time. In general, any changes in the character of the watershed affect the risk. As an area adjacent to the highway develops, the risk of flood damage to the highway and to private property increases. If flood control measures are instituted outside the highway, the risk of flood damage decreases. If a timbered watershed is likely to be logged, it may mean increased runoff and an increased risk after the timber is stripped. Such contingencies must be considered in the analysis. In

effect, the problem is one of peering into the future and making a reasonable estimate of what is likely to happen.

### Cooperative Flood Protection Projects

In many cases, it is impossible to separate storm waters into those for which adjacent property owners and those for which the highway authority would be responsible. Such problems can not be solved solely by protecting either adjacent property or the highway. A comprehensive solution which protects all concerned is needed. Such conditions give rise to cooperative projects where the interested parties share the costs. The determination of the amount of benefits received by each of the parties to a cooperative drainage scheme is seldom easy. The methods used in determining these relative benefits could well be the subject of a separate discourse.

In determining the absolute benefit, in dollars, to the highway, it is advisable to use only out of pocket costs based on past experience. User benefits seldom can be used as absolute dollar values to determine the amount to be paid by the highway authority. They may, however, be used for comparison with similar benefits accruing to the other parties to the cooperative project in order to determine the proportionate share of the total cost to be borne by each.

### Weighing Alternatives

In flood protection problems, as with other engineering problems, it is necessary to deal with alternatives. Many a worthwhile saving has been sacrificed by overlooking an alternative solution. Some engineers, catering perhaps to a sense of perfection, are prone to accept elaborate designs which give the greatest amount of flood protection. At the other extreme, there are engineers who will accept the scheme with the lowest first cost. This is forgivable if the reason is shortage of funds. Again, there are engineers who will base a decision on preconceived notions as to what is considered the most economical for the conditions. There is a middle ground between these extremes which merits exploration. Frequently, study brings up an alternative that is more desirable than those previously considered. Even when all the likely alternatives are reviewed there is a margin for error if only a summary appraisal is made. Careful evaluation of the risks involved may prove that a hastily rejected alternative involves but a minor risk, and an economic analysis may disclose that this is the most promising alternative.

### CONCLUSION

In view of the many uncertainties heretofore discussed, it must be concluded that the economics of flood protection in public works is not straightforward. It is complicated by engineering, legal and public interest factors. It is restricted by the incompleteness of engineering knowledge and it is further limited by the elusiveness of legal principles which can not be literally applied to each individual problem. Once the engineering and legal issues have been clearly defined and weighed, the keen appraisal of the intangibles remains to be done.

In spite of these difficulties and lest the reader has become discouraged by them, it must be concluded that whatever its shortcomings, economic analysis is still a useful and necessary tool in the evaluation of flood protection projects.

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FOREIGN OPERATIONS OF THE BUREAU OF PUBLIC ROADS<sup>a</sup>

A. C. Taylor,<sup>1</sup> M. ASCE  
(Proc. Paper 1076)

ABSTRACT

The paper describes how U. S. Bureau of Public Roads is engaged in extending highway technical assistance in foreign countries. The arrangements under which this program is carried on and administered and the status of the work in the several countries, the aims of the program, and the difficulties of recruiting personnel are set forth.

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The U. S. Bureau of Public Roads is engaged in foreign road programs of one type or another in Ethiopia, Turkey, Jordan, Liberia, the Philippines, Pakistan, British Guiana, Haiti, Ecuador, Panama, Costa Rica, Nicaragua, Honduras, El Salvador and Guatemala.

In Ethiopia technical assistance is furnished under a loan agreement between Ethiopia and the International Bank for Reconstruction and Development. In Turkey, Jordan, Liberia, Pakistan and the Philippines, present operations have been undertaken at the request of the International Cooperation Administration, although in both Turkey and the Philippines Public Roads' association with the country actually predated the general foreign assistance program established by the Economic Cooperation Administration, which later became the ICA. In Liberia Public Roads is also acting in a dual capacity, that is, in the field of technical assistance through agreement with ICA and as consulting engineer designated by the Liberian Government in accordance with a loan agreement with the Export-Import Bank. In British Guiana and Haiti the activities are sponsored by the ICA, but the projects are short term. In Ecuador the organization is acting as consulting engineer on a project financed under an Export-Import Bank loan. In Panama, Costa Rica, Honduras, Guatemala, El Salvador and Nicaragua primary activity involves the construction of the Inter-American Highway for which appropriations are

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made by the United States Congress to the Bureau of Public Roads and which are matched in part by the participating country. In addition, in Guatemala, the Bureau of Public Roads is furnishing engineering assistance to the ICA in connection with the construction and improvement of the Atlantic and Pacific Highways. In El Salvador, in addition to the work on the Inter-American Highway, Public Roads has cooperated with the International Bank in the preliminary engineering studies for the Pacific Highway. In Honduras Public Roads, in cooperation with ICA, has given engineering assistance and advice to the Department of Public Works in the design and construction of the "Highway of the South" which connects Tegucigalpa with the Inter-American Highway. In Nicaragua, similar assistance has been extended in the planning and construction of the highway system, which work is being financed in part by a loan from the International Bank. Also in Nicaragua, Public Roads is engaged in furnishing engineering assistance and funds for the Rama Road which will provide a highway route from the Atlantic to the Pacific.

Administratively the engineering direction and control of these projects is carried on in Washington by the Inter-American Highway Office for the work in Ecuador, Panama and the Central American countries. All other foreign projects are administered by the Foreign Projects Office. In Ethiopia, Turkey, the Philippines and Pakistan division offices have been established which, during the peak of the work correspond roughly to the division offices in the United States. In Liberia, Jordan and the Central American countries including Panama, district offices have been established. In the overseas divisions, district offices are established when the need of the work requires it and are discontinued when it is possible to centralize the administrative control. A typical division office on one of these foreign projects would be headed by a division engineer with a staff of a programming and planning engineer, a design and construction engineer, a maintenance engineer, an administrative officer, a materials engineer, a bridge engineer, and an equipment engineer. These staff engineers are of course assisted by one or more technicians. In the districts and particularly in the Central American countries the staffs are somewhat similar.

The administration in Washington is divided between the Inter-American Highway Office and the Foreign Projects Office because the work involved is markedly different. In the countries through which the Inter-American Highway passes the primary objective for many years has been the construction of the Inter-American Highway which stretches from Nuevo Laredo, Mexico, to Panama City, Panama. While considerable training was given to nationals of the countries involved and substantial technical assistance was extended to the several highway departments in the course of construction of the Inter-American Highway, the actual construction itself has been the predominant note. In the countries which are administered by the Foreign Projects Office the immediate objective in some cases has been the reconstruction of the highway system which was damaged or neglected during the war, such as the highway systems of Ethiopia or the Philippines, but the long term objective has been the establishment of strong, capable highway departments, competent to carry on highway design, construction and maintenance after the mission has been withdrawn. By insisting upon the nationals of the country doing as much of the work as possible, both in the engineering and construction field, these programs of reconstruction have been used as a training school.

A brief history of the operations in the principal areas in which work has been carried on might be of interest at this point. Public Roads began its

assistance in Central America on the Inter-American Highway after agreements were reached with the participating countries in 1929. In 1930 Congress appropriated \$50,000 for a reconnaissance survey for a road to connect North and South America. The survey was completed in 1933. Mexico elected to build their portion without assistance from the United States.

In 1934 the first United States appropriation for construction, \$1,000,000, was made available for technical aid and materials, mostly bridge steel. The participating countries furnished local materials and labor and under a co-operative agreement bridges and certain sections of road immediately functional were built, largely as demonstration projects. This work was completed in 1939.

In December 1941 Congress authorized an appropriation of \$20,000,000 for construction of the Inter-American Highway from the Mexico-Guatemala border to the Panama Canal with the proviso that the participating country pay at least one-third of the cost. Construction with this fund was started in 1942 and continued without interruption until the funds were exhausted in 1951. In the interim Congress appropriated an additional \$12,000,000 in 1943 to cover the extraordinary heavy construction in the mountains of Costa Rica. This fund did not require matching since the country did not have the financial resources to pay.

The sum of \$64,000,000 over a period of 8 years was authorized for this work in the Federal-aid acts of 1950, 1952 and 1954 but appropriations did not keep pace and the continuity of work suffered to some extent. In 1955 Congress authorized the sum of \$74,980,000 and appropriated \$62,980,000 to complete the highway as rapidly as possible and work is now going on full scale.

In Guatemala, starting at the Mexican border, there is an impassable gap of approximately 25 miles on which construction is now active. Beyond this gap between Guatemala and Costa Rica the highway is in fairly good condition to San Isidro, Costa Rica, traversing El Salvador, Honduras and Nicaragua. From San Isidro, Costa Rica, to Concepcion, Panama, there is a gap of possibly 150 miles through rough and undeveloped territory. From Concepcion to Panama City, a distance of 350 miles, a substandard road exists and is passable at all times. Since 1945 a total of 100 miles has been reconstructed and brought up to standard.

The total length of the Inter-American Highway is approximately 3200 miles, including 1600 miles in Mexico upon which no United States funds have been expended.

The following table will indicate the progress made since 1930:

	Percent, 1930	Percent, 1955
Paved	7	64
All weather	15	31
Dry weather	9	-
Impassable	69	5

Survey and construction work on the Inter-American Highway is currently active in the six republics with a total of 21 projects under construction or scheduled for construction. All of these projects are financed by project agreements with the Ministry of Public Works of the participating country in the pro rata share of funds established by law, United States two-thirds, participating country one-third. Total funds obligated for these projects is \$61,141,950 with the United States share of \$40,761,300 and cooperators \$20,380,650.

The program of technical aid to Turkey was begun in 1947. Approximately \$45.5 million has been made available since that time to finance the cost of technical assistance and the procurement of road-building and maintenance equipment. The Highway Directorate of Turkey, under the instruction of Public Roads technicians have developed their capabilities rapidly. Their highway system now comprises slightly over 15,000 miles and there are approximately 72,000 miles of secondary roads which are passable by ox-cart. Since 1948, 13,800 miles of all-weather road has been constructed.

Public Roads has been engaged in activities in Ethiopia since 1951. Prior to the war Ethiopia had a respectable highway system considering the general stage of undevelopment of the country but due to neglect during the war these roads, constructed by the Italians, deteriorated. Under the terms of the International Bank loan the Public Roads staff actually operates as the staff of the Imperial Highway Authority supplemented by such nationals as can be developed. At one time Public Roads had a staff of 40 in Ethiopia but this has been cut in half as the work progressed and Ethiopians have assumed a greater degree of responsibility. More than 90 per cent of the 3100 miles of road on the national system has been opened to all weather travel and this has reduced transport costs.

Public Roads has operated in the Philippines since 1946. The original program, which was completed in 1952, involved the reconstruction of roads, streets and bridges and the construction of such new facilities as were essential to the national economy and the national defense. \$40,040,000 were made available for this program and substantially expended. This resulted in the construction of approximately 500 bridges and reconstruction of 360 miles of high type roads and streets. Since 1952, operating under an agreement with ICA and its predecessor agencies, Public Roads has assisted in designing and placing under construction approximately 360 miles of new roads on the undeveloped Island of Mindanao to encourage resettlement by tenants on land to which they could obtain title. Approximately \$17 million of construction equipment and supplies have been furnished for this and a complementary maintenance program of the 18,000 miles of the national highway system. Here, as in Turkey, the emphasis has been upon the development of a strong highway department with as much of the work as possible being done by Filipinos. Under this plan the peak staff of 40 Public Roads people has been reduced to 11. Legislation has been passed by the Philippine Congress separating the highway function from the Bureau of Public Works and reorganizing it as the Bureau of Public Highways.

In Liberia the activities have been somewhat smaller than the countries discussed previously. Here the operation is complicated by the fact that there are so few trained Liberian engineers. Most of the Liberian staff is made up of nationals of other countries and Public Roads people find themselves in an operating as much as an advisory status. This work was started in 1951 under an Export-Import Bank loan of \$5 million. Subsequently another loan was negotiated for \$15 million most of which is to be used for highways. Efforts are being concentrated in placing in better condition the existing 1000 miles approximately of the national system and extending this system through new construction to an aggregate of 1500 miles. The present Public Roads staff is 10 people.

The assistance project in Jordan was begun in 1952. The main east-west north-south roads will be constructed under a 5-year program. Here the project is in part a work relief program since about 8,000 displaced persons are

employed to minimize unrest and to give them subsistence income. Approximately \$1.1 million is being spent for equipment to do heavy work that cannot be done by hand labor.

During 1955 a technical assistance program was undertaken in Pakistan. A division office has been established and a materials laboratory is being installed in Lahore. A district office has also been established in Dacca, East Pakistan, since this area of Pakistan is separated from the central Government at Karachi by India. A wood treatment plant is being purchased to make treated timber available for bridges and other purposes and enough equipment is being supplied to equip two demonstration projects. Approximately \$1,250,000 of United States aid have been allocated for equipment and technical aid to date.

Consultants have been sent to British Guiana and to Haiti recently to advise those governments on a highway development and maintenance program. During the past year one consultant was furnished to Korea to assist in a shop program and similar requests are received from time to time from various other countries.

All of these country projects with the exception of those involving the Inter-American Highway are as stated before, basically training programs for technicians of the host governments. This training is accomplished by holding engineering seminars in the country, by on-the-job training, by the preparation of manuals of instruction, and finally, by the training of foreign nationals in the United States.

During only the past three years a total of well over 300 highway engineers, administrators and technicians have come to the United States seeking to learn from us something of our knowledge and experience in the improvement and utilization of highways. Upon their return to their own countries, that which they have learned from us is adapted and applied to their particular conditions and problems and contributes to the improvement of highways and of highway transportation, which are accepted as essential factors in economic development and in increasing standards of living. These visitors have come from 50 or more countries located in almost all parts of the world.

For example in the State of Texas with its wide variety of topographic and climatic conditions and its thoroughly qualified staff of engineers, the Highway Department has always cooperated fully and has contributed freely of the high technical knowledge and broad practical experience of its officials, engineers and technicians, to the training of these visitors from other countries. During the past three years the Highway Department has cooperated with the Bureau of Public Roads in providing training opportunities for at least 23 individuals. These visitors have represented the countries of France and Germany in Europe; Egypt, Tanganyika, the Union of South Africa and Southern Rhodesia in Africa; Turkey and Iran in the Near East; Thailand, Australia and the Philippines in the Far East; and Colombia in South America.

It will be recognized, of course, that training requires time, tact and patience. Many of the countries in which Public Roads is working have none of the basic skills which are accepted as commonplace in this country. Some of the countries have inadequate elementary school training and little or no scientific education facilities. Those who have experienced the accumulation of engineering and mechanical skills in highway departments and other construction organizations over the past 30 or 40 years in the United States will realize how difficult it would be to attempt to develop all of those skills in a previously untrained people in a period of 6 to 8 years. None of the countries had been mechanized in the sense that the work is used here.

The foreign projects have proved to be very complex; recruiting the technical staff, the evaluation of the equipment and supplies needed, the establishment of working relationships with the host country, the scheduling of equipment purchases and the arrangements for the training of foreign engineers in the United States all require a high degree of coordination. On the latter point, for example, it might be pointed out that very often there are only a few engineers available in the host country. It is desirable to have them trained in the United States as soon as possible, but if they are sent to the United States immediately then there is no one left with whom the technical advisors can do business. Shops must be set up and mechanics must be trained before equipment is received. Operators must be trained before work is undertaken. Fortunately in most cases some time must elapse before surveys and preparation of plans are completed which presents an opportunity to accomplish training and organization before there is too much pressure by the public for visible accomplishment in the field. In many cases Public Roads is handicapped in planning country programs for highway development by reason of an utter lack of any basic data. The engineers have operated in many areas where there were not even accurate maps which showed the location of the roads and in some instances the maps indicated mountain ranges running at right angles to the position that they were later found to occupy.

The recruiting of personnel for these projects has been particularly difficult. The professional requirements for men occupying positions overseas are high. Public Roads does not have large staffs overseas and it is important, therefore, that the engineers be able to do many things without the opportunity to consult with specialists. The individual selected for this work must have many personal traits which are not always easy to find in one man. He must be a person of ability, diplomacy and sincerity. He must be willing to undergo a certain amount of hardship and to forego the pleasures associated with life in the United States. He must have a sincere liking for other people and a tolerance for the habits and customs of other races. His behavior is constantly spotlighted. Actions which would not attract any undue attention in the United States are sometimes resented by people of other nations, and every American on one of these projects is a representative of the United States and its way of life. Even the man's family must possess many of the characteristics mentioned, and thoughtless behavior or intolerance for local customs and conditions by a dependant may cause as much or more difficulty than by the employee. As a general rule, the people with whom Public Roads' engineers are associated in foreign countries are courteous, friendly and hospitable, and this feeling must be reciprocated by the people in the mission if the project is to be successful. Good health is important. In many countries the climatic conditions are severe and the sanitary conditions something less than what Americans are accustomed to.

The development of highways in foreign countries through technical assistance programs results in great impetus to the economic development of the country and to firmer bonds of friendship and understanding by the nations involved. Of all of the various technical aid programs which have been undertaken Public Roads' engineers sincerely believe that the highway program has been one of the most, if not the most, successful. New areas have been opened for production, the transportation costs of commodities have been lowered, and there has been left behind a firm foundation of engineering knowledge on which other developments can be predicted. By working intimately with people of many nations at almost every economic level, the

technicians of Public Roads have encouraged a better understanding of American ideals and of family life in this country. By introducing construction equipment to countries where it was virtually unknown before, markets have been opened up for American enterprise. From the individual point of view, we have gained tremendous satisfaction in the knowledge that we have been able to help others to help themselves.



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THE HIGHWAY SPIRAL AS A CENTERLINE FOR STRUCTURES

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(Proc. Paper 1090)

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SYNOPSIS

This paper presents a method for computing the geometry of a structure with a spiral centerline. The method is simple and precise enough for steel work. The amount of computation is no greater than that required for the multicentered curve which customarily replaces a spiral on a structure.

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When a spiraled highway is carried on a structure it is customary to approximate the spiral by a multi-centered compound curve. This approximation of the spiral permits the precise computations required for the structure. Concentric curves and radial lines are readily determined for the compound curve whereas for the spiral there are no concentric curves, and radial lines are difficult to determine.

This paper develops a method for using the spiral as a centerline for structures. Computations are no more difficult than those of the compound curve and precision is well within allowable tolerances for steel work.

The method proposed replaces the spiral, for computation purposes only, by a series of discontinuous circular arcs. The arcs are the osculating circles of the spiral at regularly spaced points along the length of the spiral. The length of each arc is the distance between the regularly spaced points and the central point of each arc is the point at which it is tangent to the spiral.

The advantages of using these discontinuous arcs instead of a compound curve are (1) the resulting curve does not deviate from the spiral by any significant amount and (2) the coordinates of the centers of the discontinuous arcs can be obtained from a table. The maximum deviation of the circular arcs from the spiral depends upon the length and sharpness of the spiral and upon the number of arcs used to approximate the spiral. For a 400-foot spiral to a 5° circular curve, with the spiral approximated by ten arcs, the

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maximum deviation is 0.003 feet. For a 200-foot spiral to a  $20^\circ$  circular curve, with the spiral approximated by ten arcs, the maximum deviation is also 0.003 feet.

To illustrate the method, the following problem will be worked out:

A 400-foot spiral to a  $5^\circ$  circular curve is to be the centerline of a structure. The main tangent at the T.S. has a bearing of Due East. A column is to be located 36 feet from the centerline on a line bearing  $S\ 45^\circ\ W$  which crosses the main tangent extended 362 feet from the T.S.

The problem is shown in Fig. 1. A and B are the centers of the osculating circles at the eighth and ninth points of the spiral, respectively. The procedure for determining the coordinates of these centers will be shown later.

C and D are the eighth and ninth points of the spiral respectively. Coordinates of the tenth points on the spiral are determined in the usual manner using standard spiral tables. The coordinates axes are the main tangent at the T.S. and the radius at the T.S.

GF is the line on which the column, F, must be located. By inspection F is closer to C than to D, so computations are based on the eighth point. E is a point on radius AC extended, distant 36 feet from C. F lies on a circular arc through E with center at A since it is permissible to replace the spiral with the osculating circle at C provided arc EF does not exceed one-twentieth of the spiral length.

The length and bearing of line AG are, by inverse computation, 1449.525 feet and  $S\ 8^\circ\ 00'\ 47''\ 7\ E$ , respectively. In triangle AGF, sides AG and AF are now known and so is angle AGF. Solving, angle FAG is  $0^\circ\ 58'\ 00''\ 2$  and side FG is 31.015. The coordinates of F are computed to be -21.931, +340.069.

The remaining step is to determine the elevation of the roadway at F. It would appear that to do so, the spiral radius passing through F must be located. However, as will be shown, no appreciable error is introduced by assuming that radius AF is the spiral radius at H. The difference in the stationing of point H and the stationing of the exact point on the spiral radius depends upon the distance of point F from the centerline, the length of spiral, and the degree of the circular curve. In the example given, the error in stationing is 0.010 feet. The maximum possible value of the error for the spiral of the example is 0.016 feet for a point 36 feet from the spiral centerline.

The error in elevation resulting from an error in stationing of 0.02 feet would be negligible except, perhaps, on steep ramps. However, on ramps the length of spiral would be much less than 400 feet and the width would be much less than 72 feet. For example, for a 200-foot spiral to a  $20^\circ$  circular curve the maximum error in centerline stationing for a point 15 feet from the centerline, would be 0.013. With an 8% grade, the resulting error in elevation would be 0.001 feet.

The following definitions are required by subsequent development:

- $D_1$  = degree of circular curve, degrees
- D = degree of osculating circle at any point, degrees
- L = length of spiral, feet
- $\ell$  = length of spiral from T.S. to any intermediate point on spiral, feet
- $\theta_s$  = total spiral angle, degrees
- $\theta$  = spiral angle from T.S. to any intermediate point on the spiral, degrees

The derivation of the equations of the x- and y-coordinates of the locus of the osculating circle centers may be readily shown by reference to Fig. 2. Point A is any point of the spiral distant  $\ell$  from the T.S. The spiral angle to

A is  $\theta$ . Letting  $r$  be the radius of the osculating circle at A, and  $R$  the radius of the circular curve,

$$r = \frac{RL}{\ell} \quad (1)$$

The coordinates of A are

$$x = \ell \left[ 1 - \frac{\theta^2}{5(2!)} + \frac{\theta^4}{9(4!)} - \frac{\theta^6}{13(6!)} + \dots \right] \quad (2)$$

and

$$y = \ell \left[ \frac{\theta}{3} - \frac{\theta^3}{7(3!)} + \frac{\theta^5}{11(5!)} - \frac{\theta^7}{15(7!)} + \dots \right] \quad (3)$$

$\theta$  being expressed in radians, and  $x$ ,  $y$ , and  $\ell$  in feet. Calling the coordinates of O, the center of the osculating circle,  $x'$  and  $y'$ ,

$$x' = x - r \sin \theta \quad (4)$$

and

$$y' = y + r \cos \theta \quad (5)$$

Substituting series expansions for sine and cosine, and simplifying,

$$x' = \ell \left[ \frac{1}{2} - \frac{\theta^2}{10(3!)} + \frac{\theta^4}{18(5!)} - \frac{\theta^6}{26(7!)} + \dots \right] \quad (6)$$

and

$$y' = \ell \left[ \frac{1}{2\theta} + \frac{\theta}{6(2!)} - \frac{\theta^3}{14(4!)} + \frac{\theta^5}{22(6!)} - \dots \right] \quad (7)$$

Changing to degrees, the equations become

$$x' = \ell \left[ \frac{1}{2} - 0.5077 \theta^2 10^{-5} + 0.429 \theta^4 10^{-10} - \dots \right] \quad (8)$$

and

$$y' = \ell \left[ \frac{28.64789}{\theta} + 0.1454 \theta 10^{-2} - 0.158 \theta^3 10^{-7} + \dots \right] \quad (9)$$

For value of  $\theta$  up to  $10^\circ$ , only the first two terms are required in the expression for  $x'$  and only the first three terms in the expression for  $y'$ .

Values of  $x'$  and  $y'$  for a one-foot spiral are tabulated for value of  $\theta$  from  $0^\circ$  to  $10^\circ$  by increments of  $0.01$  in Table 1. To obtain the coordinates of the center of an osculating circle to any point on a given spiral: (1) compute the value of  $\theta$  to the point; (2) look up the tabulated value of  $x'$  and  $y'$  for that value of  $\theta$ ; and (3) multiply the tabulated value of  $x'$  and  $y'$  by the length of the spiral from the T.S. to the given point on the spiral.

It may be readily seen that interpolation for values of  $x'$  in Table 1 will

yield accurate results but that the same thing is not true for values of  $y'$  because of the rapid variation of  $y'$ . In order to permit interpolation for values of  $y'$ , it is necessary to tabulate separately the sum of all terms after the first in Eq. 9. Accurate interpolation is possible between these tabular values. To obtain the corresponding value of  $y'$ , the quantity  $28.64789 \div \theta$  must be added to the interpolated value.

Computation of the coordinates of the osculating circle centers for the illustrative problem is shown in Table 2. Values of  $\ell$  to the tenth points of the spiral are shown in Col. 2. Values of  $\theta$  are obtained from the equation

$$\theta = \left[ \frac{\ell}{L} \right]^2 \theta_s \quad (10)$$

and are shown in Col. 3. The value of  $\theta_s$  is

$$\theta_s = \frac{D_1 L}{200} = \frac{5 \cdot 400}{200} = 10^\circ \quad (11)$$

The values of  $x'$  and  $y'$  for a one-foot spiral are obtained from Table 1 and shown in Cols. 4 and 5. Values of  $x'$  and  $y'$  for the 400-foot spiral are obtained by multiplying Col. 3 by Cols. 4 and 5, and are shown in Cols. 6 and 7. For convenience in subsequent computations the values of  $D$  and  $R$  are listed in Cols. 8 and 9.

Proof that the error in stationing along the centerline made by assuming that point H of Fig. 1 is on the spiral radius passing through point F, is negligible, may be obtained by reference to Fig. 3. Here CNH is the centerline spiral with C a tenth point of the spiral. The T.S. and S.C. (not shown) are to the left and right of C, respectively. A is the center of the osculating circle at C. F is a point on the structure previously located, distant CE from the spiral centerline and, therefore, assumed to lie on a circular arc with center at A and radius equal to the radius of the osculating circle at C plus CE. M is the center of the osculating circle to the spiral at N, point F lying on radius MN extended.

Letting  $k$  equal the distance along the spiral from T.S. to C, and  $m$  equal the length of arc CN, the spiral angle to N is

$$\theta_N = \left[ \frac{k+m}{L} \right]^2 \theta_s = \left[ \frac{k+m}{L} \right]^2 \frac{D_1 L}{200} \quad (12)$$

or

$$\theta_N = \left[ \frac{k}{L} \right]^2 \frac{D_1 L}{200} + \frac{2km}{L^2} \frac{D_1 L}{200} + \left[ \frac{m}{L} \right]^2 \frac{D_1 L}{200} \quad (13)$$

The first term is the spiral angle to C which will be designated  $\theta_c$ . The second term may be rewritten

$$\frac{2km}{L^2} \frac{D_1 L}{200} = \frac{m}{100} \frac{kD_1}{L} \quad (14)$$

Since  $\frac{kD_1}{L}$  is the degree of the osculating circle at C, the product of this degree and the length of arc in stations is the angle CAN which will be designated  $\alpha$ .

The third term of Eq. 13 may be rewritten

$$\left[\frac{m}{L}\right]^2 \frac{D_1 L}{200} \frac{k}{k} = \frac{m}{2k} \frac{m}{100} \frac{k D_1}{L} = \frac{m}{2k} \alpha \quad (15)$$

This term is the angle FNP which will be designated  $d\alpha$ . Letting  $\theta_C$  and  $\theta_N$  be the spiral angles to points C and N on the spiral respectively, Eq. 13 becomes

$$\theta_N = \theta_C + \alpha + d\alpha \quad (16)$$

If N is closer to the T.S. than C the equation becomes

$$\theta_N = \theta_C - \alpha + d\alpha \quad (17)$$

In locating F the bearing of AF is computed so angle CAH is readily determined as is arc CH. By assuming angle CAH equal to  $\alpha$  and arc CH equal to  $m$ , a very close approximation of  $d\alpha$  may be obtained. This value of  $d\alpha$  is used to obtain arc NH (This assumes that angles FNP and NFH are equal which is true for all practical purposes). Arc NH is subtracted from arc CH to obtain arc AC which will be correct to the nearest thousandth.

In the illustrative example angle CAH is  $0^\circ 38' 47.5''$  so arc CH is 16.163 feet. Using this value for  $m$ , angle CAH as  $\alpha$  and  $k$  equal to 320 feet,

$$d\alpha = \frac{16.163}{2 \cdot 320} (0.38 - 47.5) = 58.8''$$

Arc NH is equal to the product of 36 and the sine of  $58.8''$  or 0.0103 feet. By successive approximations it may be shown that the correct value of arc NH is 0.0100 feet.

Since this error in stationing has no effect on horizontal location but only on elevation, it is obvious that it is negligible. The maximum possible error in stationing for the illustrative spiral due to the assumption, is 0.016 feet for a point 36 feet from the spiral centerline.

### CONCLUSIONS AND COMMENTS

The advantage of the method herein proposed is that it makes possible the use of comparable transitions throughout the length of a highway. While the multi-centered curve which approximates a spiral may be a satisfactory substitute for a given spiral, it is still a substitute. The more it departs from spirals used elsewhere on the alignment, the less satisfactory a substitute it becomes.

The amount of computation involved in the proposed method is about the same as that of the conventional method. The extra work resulting from the use of ten rather than three or four circular arcs is offset by the fact that the centers of the ten arcs may be obtained directly from tables.

While the precision of the method decreases as the length of spiral and degree of circular curve increase, it is still remarkably accurate for sharp spirals. On a 150-foot spiral to a  $30^\circ$  circular curve, the maximum departure from the spiral is less than one-thirty-second of an inch horizontally. Errors in elevation are negligible.

$\theta$	$x'$	$y'$	$(y' - \frac{180}{2\pi\theta})$
0.0	0.500 00	infinity	0.000 00
0.1	0	286.479 04	15
0.2	0	143.239 74	29
0.3	0	95.493 40	44
0.4	0	71.620 31	58
0.5	0.500 00	57.296 51	0.000 73
0.6	0	47.747 36	87
0.7	0	40.926 58	102
0.8	0	35.811 03	116
0.9	0	31.832 30	131
1.0	0.499 99	28.649 34	0.001 45
1.1	9	26.045 14	160
1.2	9	23.874 99	174
1.3	9	22.038 73	189
1.4	9	20.464 81	204
1.5	0.499 99	19.100 77	0.002 18
1.6	9	17.907 26	233
1.7	9	16.854 17	247
1.8	8	15.918 11	262
1.9	8	15.080 60	276
2.0	0.499 98	14.326 85	0.002 91
2.1	8	13.644 90	305
2.2	8	13.024 97	320
2.3	7	12.458 95	334
2.4	7	11.940 11	349
2.5	0.499 97	11.462 79	0.003 64

$\theta$	$x'$	$y'$	$(y' - \frac{180}{2\pi\theta})$
2.5	0.499 968	11.462 792	0.003 636
2.6	66	11.022 200	3 781
2.7	63	10.614 256	3 927
2.8	60	10.235 461	4 072
2.9	57	9.882 800	4 217
3.0	0.499 954	9.553 659	0.004 363
3.1	51	9.245 763	4 508
3.2	48	8.957 119	4 654
3.3	45	8.685 978	4 799
3.4	41	8.430 794	4 944
3.5	0.499 938	8.190 201	0.005 090
3.6	34	7.962 982	5 235
3.7	30	7.748 053	5 381
3.8	27	7.544 444	5 526
3.9	23	7.351 284	5 671
4.0	0.499 919	7.167 789	0.005 817
4.1	15	6.993 252	5 962
4.2	11	6.827 033	6 107
4.3	06	6.668 553	6 253
4.4	02	6.517 282	6 398
4.5	0.499 897	6.372 741	0.006 544
4.6	93	6.234 491	6 689
4.7	88	6.102 130	6 834
4.8	83	5.975 290	6 980
4.9	78	5.853 633	7 125
5.0	0.499 873	5.736 848	0.007 270

Table 1

$\theta$	$x'$	$y'$	$(y' - \frac{180}{2\pi\theta})$
5.0	0.499 873	5.736 848	0.007 270
5.1	68	5.624 649	7 416
5.2	63	5.516 770	7 561
5.3	57	5.412 968	7 706
5.4	52	5.313 016	7 851
5.5	0.499 846	5.216 704	0.007 997
5.6	41	5.123 837	8 142
5.7	35	5.034 233	8 287
5.8	29	4.947 724	8 433
5.9	23	4.864 152	8 578
6.0	0.499 817	4.783 372	0.008 723
6.1	11	4.705 244	8 868
6.2	05	4.629 641	9 014
6.3	799	4.556 443	9 159
6.4	92	4.485 537	9 304
6.5	0.499 786	4.416 817	0.009 450
6.6	79	4.350 184	9 595
6.7	72	4.285 544	9 740
6.8	65	4.222 810	9 885
6.9	58	4.161 898	0.010 030
7.0	0.499 751	4.102 731	0.010 176
7.1	44	4.045 235	10 321
7.2	37	3.989 340	10 466
7.3	30	3.934 980	10 611
7.4	22	3.882 093	10 756
7.5	0.499 715	3.830 620	0.010 902

$\theta$	$x'$	$y'$	$(y' - \frac{180}{2\pi\theta})$
7.5	0.499 715	3.830 620	0.010 902
7.6	07	3.780 506	11 047
7.7	699	3.731 697	11 192
7.8	91	3.684 144	11 337
7.9	83	3.637 798	11 482
8.0	0.499 675	3.592 614	0.011 627
8.1	67	3.548 549	11 773
8.2	59	3.505 563	11 918
8.3	50	3.463 616	12 063
8.4	42	3.422 671	12 208
8.5	0.499 633	3.382 693	0.012 353
8.6	25	3.343 648	12 498
8.7	16	3.305 504	12 643
8.8	07	3.268 230	12 788
8.9	598	3.231 797	12 933
9.0	0.499 589	3.196 177	0.013 078
9.1	80	3.161 343	13 223
9.2	71	3.127 270	13 368
9.3	61	3.093 932	13 514
9.4	52	3.061 306	13 659
9.5	0.499 542	3.029 371	0.013 804
9.6	32	2.998 104	13 949
9.7	23	2.967 484	14 094
9.8	13	2.937 493	14 239
9.9	03	2.908 110	14 384
10.0	0.499 493	2.879 318	0.014 529

Table 1 (continued)

1	2	3	4	5	6	7	8	9
Point	$\alpha$	$\theta$	1-foot Spiral		400-foot Spiral		D	R
			$x'$	$y'$	$x'$	$y'$		
1	40	0.1	0.50000	286.47904	20.000	11,459.162	0.5	11,459.156
2	80	0.4	0.50000	71.62031	40.000	5,729.625	1.0	5,729.578
3	120	0.9	0.50000	31.83230	60.000	3,819.876	1.5	3,819.719
4	160	1.6	0.49999	17.90726	79.998	2,865.161	2.0	2,864.789
5	200	2.5	0.499968	11.462792	99.994	2,292.558	2.5	2,291.831
6	240	3.6	0.499934	7.962982	119.984	1,911.116	3.0	1,909.859
7	280	4.9	0.499878	5.853633	139.966	1,639.017	3.5	1,637.022
8	320	6.4	0.499792	4.485537	159.933	1,435.372	4.0	1,432.394
9	360	8.1	0.499667	3.548549	179.880	1,277.478	4.5	1,273.240
10	400	10.0	0.499493	2.879318	199.797	1,151.727	5.0	1,145.916

Table 2

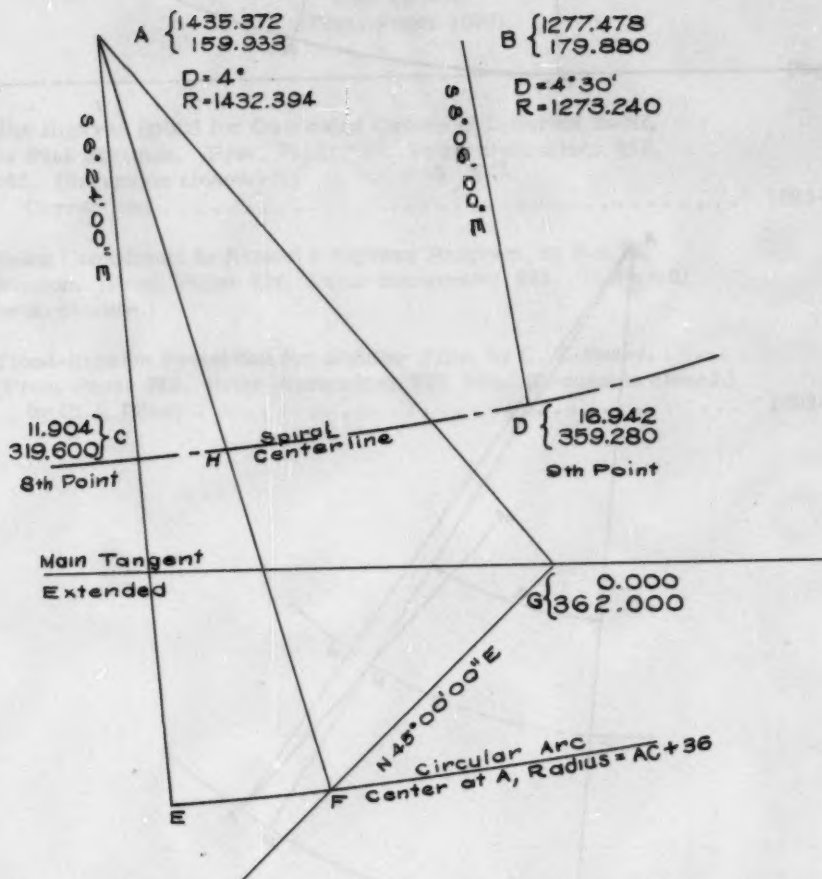
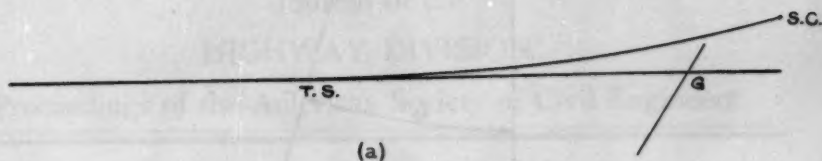


Fig. 1

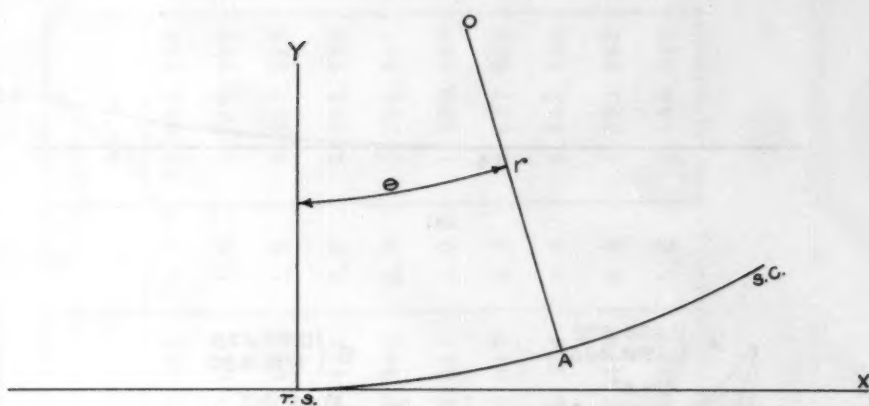


Fig. 2

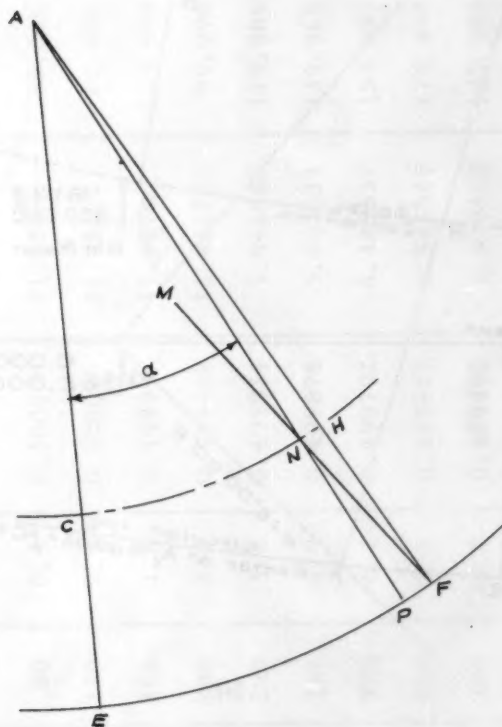


Fig. 3

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Journal of the  
HIGHWAY DIVISION  
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## CONTENTS

DISCUSSION  
(Proc. Paper 1093)

	Page
The Highway Spiral for Combining Curves of Different Radii, by Paul Hartman. (Proc. Paper 703. Prior discussion: 810, 985, Discussion closed.)	
Corrections .....	1093-3
Using Consultants to Expand a Highway Program, by Rex M. Whitton. (Proc. Paper 824. Prior discussion: 985. There will be no closure.)	
Flood-Erosion Protection for Highway Fills, by C. J. Posey. (Proc. Paper 783. Prior discussion: 877, 985. Discussion closed.) by C. J. Posey .....	1093-5

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Note: Paper 1093 is part of the copyrighted Journal of the Highway Division of the  
American Society of Civil Engineers, Vol. 82, HW 3, October, 1956.

Journal of the  
HIGHWAY DIVISION  
Proceedings of the American Society of Civil Engineers

CONTENTS	
DISCUSSION	
(Paper 1957-1)	

The Highway Board for Combining Curves of Different Radii  
By John H. Heston, 1957, Paper 1957-1, 10 pp. (Discussion closed)  
1957-1

Using Computers to Layout a Highway Program for the 40  
Mile (Paper 1957-2, 1957, Discussion closed, 10 pp. and  
on on charts)  
Road-Exclusion Protection for Highway 1957, By C. E. Fowey,  
1957, Paper 1957-2, 1957, Discussion closed, 10 pp. and  
on on charts, 1957-2

1957-1

Discussion of  
**"THE HIGHWAY SPIRAL FOR COMBINING CURVES  
 OF DIFFERENT RADII"**

by Paul Hartman  
 (Proc. Paper 703)

**CORRECTION.**—In Eq 36, page 985-7,  $\frac{R_3}{R_6}$  should be changed to  $\frac{R_3}{R_c}$ .

THE HIGHWAY BUREAU AND THE  
DEPARTMENT OF TRANSPORTATION

BY  
J. H. HARRIS

COLLECTED BY J. H. HARRIS, 1917-1918  
PUBLISHED BY THE BUREAU OF PUBLIC AFFAIRS

Discussion of  
"FLOOD-EROSION PROTECTION FOR HIGHWAY FILLS"

by C. J. Posey  
(Proc. Paper 783)

C. J. POSEY,<sup>1</sup> M. ASCE.—The writer wishes to thank each of the discussors, whose contributions do much to fill the gap between the original paper and its title, which was perhaps too inclusive. Mr. Matthes' report on European use of "rock sausages" and Mr. Lane's reference to ancient Chinese use are especially welcome since they show the origins of this device and testify to its long history of successful application. The writer's approach, which ignored the literature, at least in the first stages of the investigation, may seem wasteful, but it is likely that if the customary historical review had been made before the experiments were started the interesting observations of the mechanism of rip-rap protection would not have been made, and the necessity for T-V grading of protective layers not discovered. These observations point the way to developing a technique of rock sausage protection that is completely dependable.

The figures comparing the cost and abrasive resistance of steel wire and "ordinary galvanized iron wire" cited by Mr. Matthes cause one to wonder whether the wires were comparable to those used in this country, unless Dr. Kreutner was using stainless steel wire. The writer believes that for the protection of the flanks of embankments against water flowing down the slope, spiral woven mesh is greatly preferable to hexagonal mesh, since the superior springiness of the spiral weave insures that the sausage unit will maintain good compressive strength.

Messrs. Izzard and Bradley have contributed a most sound and eloquent argument for the reexamination of the basis for the prevalent policy of always constructing elevated road embankments. Their discussion deserves careful study by every designer of highway bridge crossings.

Professor Kindsvater rightly emphasizes the importance of the hydraulic flow characteristics, and points out that if "surface flows" can be maintained over a wider range, less erosion resistance may be necessary. Although experience has taught the writer to be cautious in predicting when and where erosion will be more or less severe, he is willing to agree with Professor Kindsvater that surface flows are likely to be less erosive than plunging flows. The tests described in the paper were all made with minimum tailwater since it was desired to subject the embankments to the most severe test, and preliminary experiments showed the condition of minimum tailwater to be even more severe than the case with a hydraulic jump forming on the slope.

The hydraulic data being obtained by Professor Kindsvater are of course essential if the economic balance envisaged by Messrs. Izzard and Bradley is to be evaluated. The money values involved are evidently enormous, which gives special urgency to the hydraulic experimentation.

1. Prof. and Head, Dept. of Civ. Eng., State Univ. of Iowa, Iowa City, and Director, Rocky Mountain Hydr. Lab., Allenspark, Colo.

Too late to be published as a separate discussion, the writer received through Professor Kindsvater a communication from Mr. Hubert E. Snyder, M. ASCE, citing the case of a highway fill which was built across a water-supply reservoir with the expectation that it would occasionally be overtopped by flood waters. The fill was said to have successfully withstood one flood, only to be washed out under a later flood of approximately the same magnitude. In the interval between floods a plate-type guard rail was said to have been installed, and it was thought that the presence of the guard rail and posts caused the failure. This seems likely to the writer, by comparison with other erosion tests he has made. That considerable differences in the flow pattern might be expected is shown by the data presented by Professor Kindsvater. Evidently the effect of handrails on hydraulic and erosion characteristics needs to be further investigated. It is the writer's opinion that cable guard rails carried by slender posts, preferably of steel and carefully installed between sausages would not appreciably affect the erosion resistance of a properly built fill.

Mr. Neeley describes an application of rock sausage protection which has provided an economical solution to a difficult erosion problem. Again, the writer would suggest spiral-woven fencing which, though not as widely available as fencing marketed for agricultural purposes, is better for the purpose and should be cheaper in quantity because it is easier to manufacture and much easier to "sew" in the field.

#### ERRATA

in the paper (Paper No. 783, August 1955)

Page 783-2, first paragraph under "Some Possible Ways of Improving the Modern Type of Valley Crossing." Change second word of this paragraph from "most" to "many."

Page 783-3, eleventh line from top of page. Change "safe" to "sufficient."

Page 783-3, third from last line of 4th paragraph, change "main currents" to "principal currents."

Page 783-7, third sentence of second paragraph should read "The grading was not quite right according to the T-V requirements of the layer next underneath and was somewhat too small for the wire mesh openings."

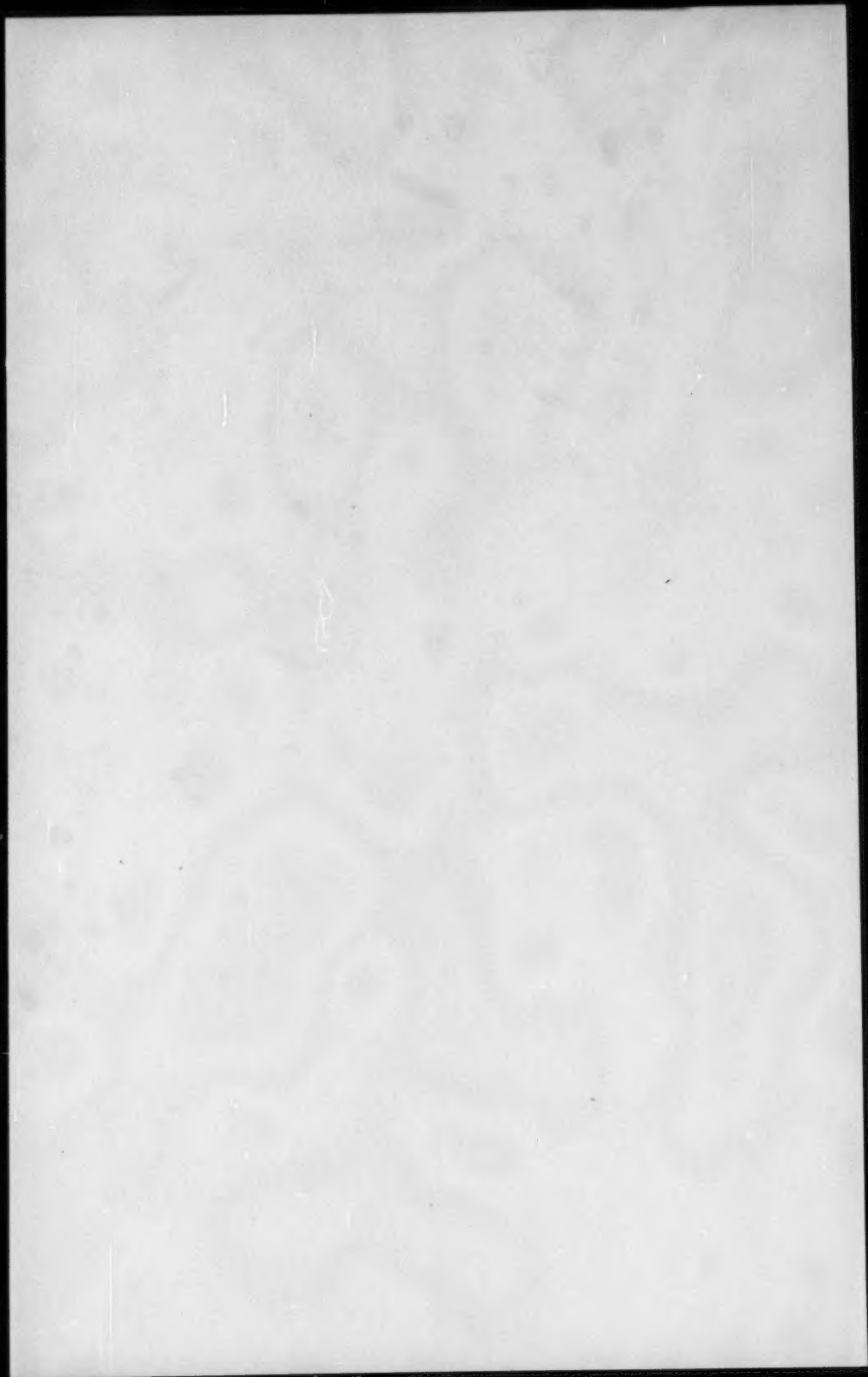
Page 783-10, paragraph ending about the middle of page. Insert "or" between "pliers" and "abutments."

in Mr. Lane's discussion (Paper 877)

Page 877-4, at end of sixth line of Lane's second paragraph "rise" should be "use."

in Mr. Matthes' discussion (Paper 877)

Page 877-3, fourth line from bottom of page, "sawing" should be "sewing."





# PROCEEDINGS PAPERS

The technical papers published in the past year are identified by number below. Technical-division sponsorship is indicated by an abbreviation at the end of each Paper Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways and Harbors (WW) divisions. Papers sponsored by the Board of Direction are identified by the symbols (BD). For titles and order coupons, refer to the appropriate issue of "Civil Engineering." Beginning with Volume 82 (January 1956) papers were published in Journals of the various Technical Divisions. To locate papers in the Journals, the symbols after the paper numbers are followed by a numeral designating the issue of a particular Journal in which the paper appeared. For example, Paper 861 is identified as 861 (SM1) which indicates that the paper is contained in issue 1 of the Journal of the Soil Mechanics and Foundations Division.

## VOLUME 81 (1955)

OCTOBER: 809 (ST), 810 (HW)<sup>c</sup>, 811 (ST), 812 (ST)<sup>c</sup>, 813 (ST)<sup>c</sup>, 814 (EM), 815 (EM), 816 (EM), 817 (EM), 818 (EM), 819 (EM)<sup>c</sup>, 820 (SA), 821 (SA), 822 (SA)<sup>c</sup>, 823 (HW), 824 (HW).

NOVEMBER: 825 (ST), 826 (HY), 827 (ST), 828 (ST), 829 (ST), 830 (ST), 831 (ST)<sup>c</sup>, 832 (CP), 833 (CP), 834 (CP), 835 (CP)<sup>c</sup>, 836 (HY), 837 (HY), 838 (HY), 839 (HY), 840 (HY), 841 (HY)<sup>c</sup>.

DECEMBER: 842 (SM), 843 (SM)<sup>c</sup>, 844 (SU), 845 (SU)<sup>c</sup>, 846 (SA), 847 (SA), 848 (SA)<sup>c</sup>, 849 (ST)<sup>c</sup>, 850 (ST), 851 (ST), 852 (ST), 853 (ST), 854 (CO), 855 (CO), 856 (CO)<sup>c</sup>, 857 (SU), 858 (BD), 859 (BD), 860 (BD).

## VOLUME 82 (1956)

JANUARY: 861 (SM1), 862 (SM1), 863 (EM1), 864 (SM1), 865 (SM1), 866 (SM1), 867 (SM1), 868 (HW1), 869 (ST1), 870 (EM1), 871 (HW1), 872 (HW1), 873 (HW1), 874 (HW1), 875 (HW1), 876 (EM1)<sup>c</sup>, 877 (HW1)<sup>c</sup>, 878 (ST1)<sup>c</sup>.

FEBRUARY: 879 (CP1), 880 (HY1), 881 (HY1)<sup>c</sup>, 882 (HY1), 883 (HY1), 884 (IR1), 885 (SA1), 886 (CP1), 887 (SA1), 888 (SA1), 889 (SA1), 890 (SA1), 891 (SA1), 892 (SA1), 893 (CP1), 894 (CP1), 895 (PO1), 896 (PO1), 897 (PO1), 898 (PO1), 899 (PO1), 900 (PO1), 901 (PO1), 902 (AT1)<sup>c</sup>, 903 (IR1)<sup>c</sup>, 904 (PO1)<sup>c</sup>, 905 (SA1)<sup>c</sup>.

MARCH: 906 (WW1), 907 (WW1), 908 (WW1), 909 (WW1), 910 (WW1), 911 (WW1), 912 (WW1), 913 (WW1)<sup>c</sup>, 914 (ST2), 915 (ST2), 916 (ST2), 917 (ST2), 918 (ST2), 919 (ST2), 920 (ST2), 921 (SU1), 922 (SU1), 923 (SU1), 924 (ST2)<sup>c</sup>.

APRIL: 925 (WW2), 926 (WW2), 927 (WW2), 928 (SA2), 929 (SA2), 930 (SA2), 931 (SA2), 932 (SA2)<sup>c</sup>, 933 (SM2), 934 (SM2), 935 (WW2), 936 (WW2), 937 (WW2), 938 (WW2), 939 (WW2), 940 (SM2), 941 (SM2), 942 (SM2)<sup>c</sup>, 943 (EM2), 944 (EM2), 945 (EM2), 946 (EM2)<sup>c</sup>, 947 (PO2), 948 (PO2), 949 (PO2), 950 (PO2), 951 (PO2), 952 (PO2)<sup>c</sup>, 953 (HY2), 954 (HY2), 955 (HY2)<sup>c</sup>, 956 (HY2), 957 (HY2), 958 (SA2), 959 (PO2), 960 (PO2).

MAY: 961 (IR2), 962 (IR2), 963 (CP2), 964 (CP2), 965 (WW3), 966 (WW3), 967 (WW3), 968 (WW3), 969 (WW3), 970 (ST3), 971 (ST3), 972 (ST3)<sup>c</sup>, 973 (ST3), 974 (ST3), 975 (WW3), 976 (WW3), 977 (IR2), 978 (AT2), 979 (AT2), 980 (AT2), 981 (IR2), 982 (IR2)<sup>c</sup>, 983 (HW2), 984 (HW2), 985 (HW2)<sup>c</sup>, 986 (ST3), 987 (AT2), 988 (CP2), 989 (AT2).

JUNE: 990 (PO3), 991 (PO3), 992 (PO3), 993 (PO3), 994 (PO3), 995 (PO3), 996 (PO3), 997 (PO3), 998 (SA3), 999 (SA3), 1000 (SA3), 1001 (SA3), 1002 (SA3), 1003 (SA3)<sup>c</sup>, 1004 (HY3), 1005 (HY3), 1006 (HY3), 1007 (HY3), 1008 (HY3), 1009 (HY3), 1010 (HY3)<sup>c</sup>, 1011 (PO3)<sup>c</sup>, 1012 (SA3), 1013 (SA3), 1014 (SA3), 1015 (HY3), 1016 (SA3), 1017 (PO3), 1018 (PO3).

JULY: 1019 (ST4), 1020 (ST4), 1021 (ST4), 1022 (ST4), 1023 (ST4), 1024 (ST4)<sup>c</sup>, 1025 (SM3), 1026 (SM3), 1027 (SM3), 1028 (SM3)<sup>c</sup>, 1029 (EM3), 1030 (EM3), 1031 (EM3), 1032 (EM3), 1033 (EM3)<sup>c</sup>.

AUGUST: 1034 (HY4), 1035 (HY4), 1036 (HY4), 1037 (HY4), 1038 (HY4), 1039 (HY4), 1040 (HY4), 1041 (HY4)<sup>c</sup>, 1042 (PO4), 1043 (PO4), 1044 (PO4), 1045 (PO4), 1046 (PO4)<sup>c</sup>, 1047 (SA4), 1048 (SA4)<sup>c</sup>, 1049 (SA4), 1050 (SA4), 1051 (SA4), 1052 (HY4), 1053 (SA4).

SEPTEMBER: 1054 (ST5), 1055 (ST5), 1056 (ST5), 1057 (ST5), 1058 (ST5), 1059 (WW4), 1060 (WW4), 1061 (WW4), 1062 (WW4), 1063 (WW4), 1064 (SU2), 1065 (SU2), 1066 (SU2)<sup>c</sup>, 1067 (ST5)<sup>c</sup>, 1068 (WW4)<sup>c</sup>, 1069 (WW4).

OCTOBER: 1070 (EM4), 1071 (EM4), 1072 (EM4), 1073 (EM4), 1074 (HW3), 1075 (HW3), 1076 (HW3), 1077 (HY5), 1078 (SA5), 1079 (SM4), 1080 (SM4), 1081 (SM4), 1082 (HY5), 1083 (SA5), 1084 (SA5), 1085 (SA5), 1086 (PO5), 1087 (SA5), 1088 (SA5), 1089 (SA5), 1090 (HW3), 1091 (EM4)<sup>c</sup>, 1092 (HY5)<sup>c</sup>, 1093 (HW3)<sup>c</sup>, 1094 (PO5)<sup>c</sup>, 1095 (SM4)<sup>c</sup>.

c. Discussion of several papers, grouped by Divisions.

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